KAIST-TH 00/3

Effects of flavor conserving CP violating phases in SUSY models

P. Ko

Department of Physics, KAIST, Taejon 305-701, KOREA

E-mail: [a] *pko@muon.kaist.ac.kr*

Abstract

I summarize our recent works on the effects of flavor conserving CP violating phases in SUSY models on B and K phenomenology.

I. INTRODUCTION

The minimal supersymmetric standard model (MSSM) has many CP violating (CPV) phases beyond the KM phase in the standard model (SM). These SUSY CPV phases, depending on their flavor structures, are strongly constrained by ϵ_K or electron/neutron electric dipole moment (EDM), and have been considered very small ($\delta \leq 10^{-2}$ for $M_{\rm SUSY} \sim O(100)$ GeV). [1] Another way to solve these problems is to consider effective SUSY models, where decouplings of the 1st/2nd generation sfermions are invoked to evade the EDM constraints and also SUSY FCNC/CP problems. [2] In such cases, these new SUSY phases may affect B and K physics. One strong motivation for new CP violating phases beyond the KM phase is related with the baryon number asymmetry of the universe. Electroweak baryogenesis is possible in a certain region of the MSSM parameter space, especially for light stop (120 GeV $\leq m_{\tilde{t}_1} \leq$ 175 GeV) with CP violating phases in μ and A_t parameters. [3] This light stop and new CP violating phases in μ and A_t parameters can affect B and K physics, although these phases are flavor conserving. In this talk, we report our three recent works related with this subject. [4–6] The topics covered here are the following : the effects of ϕ_μ and ϕ_{A_t} on B physics in the MMSSM, and fully supersymmetric CP violations in the kaon system.

II. EFFECTS OF μ AND A_T PHASES ON B PHYSICS IN THE MORE MINIMAL SUPERSYMMETRIC STANDARD MODEL (MMSSM)

In the MMSSM we consider in this section, only the third family squarks and charginos can be light enough to affect $B \to X_s \gamma$ and $B^0 - \overline{B^0}$ mixing. We also ignore possible flavor changing squark mass matrix elements that could generate gluino-mediated flavor changing

neutral current (FCNC) process, dicussions of which can be found in the literatures, [7,8], for example. Ignoring such contributions, the only source of the FCNC in our model may be attributed to the CKM matrix, whereas there are new CPV phases coming from the phases of μ and A_t parameters in the flavor preserving sector in addition to the KM phase δ_{KM} in the flavor changing sector.

Even if the 1st/2nd generation squarks are very heavy and degenerate, there is another important edm constraints considered by Chang, Keung and Pilaftsis (CKP) for large $\tan\beta$. [9] This constraint comes from the two loop diagrams involving stop/sbottom loops, and is independent of the masses of the 1st/2nd generation squarks. Therefore, this CKP edm constraints can not be simply evaded by making the 1st/2nd generation squarks very heavy, and it turns out that this puts a strong constraint on the possible new phase shift in the $B^0 - \overline{B^0}$ mixing. We scanned over the broad parameter space and imposed the various experimental constraints including $BR(B \to X_s \gamma)$.It has to be emphasized that this parameter space is larger than that in the constrained MSSM (CMSSM) where the universality of soft terms at the GUT scale is assumed.

The $B^0 - \overline{B^0}$ mixing is generated by the box diagrams with $u_i - W^\pm (H^\pm)$ and $\tilde{u}_i - \chi^\pm$ running around the loops in addition to the SM contribution. The gluino and neutralino contributions are negligible in our model. The chargino exchange contributions to $B^0 - \overline{B^0}$ mixing is generically complex relative to the SM contributions, and this effect can be in fact significant for large $\tan\beta (\simeq 1/\cos\beta)$, since the chargino contribution is proportional to $(m_b / M_W \cos\beta)^2$. However, the CKP edm constraint puts a strong constraint for large $\tan\beta$ case. The result is that the CKP edm constraint on $2\theta_d$ is in fact very important for large $\tan\beta$, and we have $|2\theta_d| \leq 1^\circ$. This observation is important for the CKM phenomenology, since time-dependent CP asymmetries in neutral B decays into $J/\psi K_S, \pi\pi$ etc. would still measure directly three angles of the unitarity triangle even if ϕ_{A_t} and ϕ_μ are nonzero. We also find that the dilepton asymmetry (proportional to $\mathrm{Re}(\epsilon_B)$) is very small as in the SM, but Δm_B can be enhanced as much as 60%. See Ref. [4] for more details.

The radiative decay of B mesons, $B \to X_s \gamma$, is described by the effective Hamiltonian including (chromo)magnetic dipole operators. Interference between $b \to s\gamma$ and $b \to sg$ (where the strong phase is generated by the charm loop via $b \to c\bar{c}s$ vertex) can induce direct CP violation in $B \to X_s \gamma$. [10] The SM predicts a very small asymmetry smaller than 0.5%, so the larger asymmetry will be a clean signal for new source of CP violating phases. In our model, we find that $A_{\rm CP}^{b \to s\gamma}$ can be as large as $\simeq \pm 16\%$ if chargino is light enough, even if we impose the edm constraints. So this mode may be one of the good place for probing new CPV phases.

Next let us next consider R_{ll}, the ratio of the branching ratio for $B \to X_s l^+ l^-$ in our model to that in the SM. In the presence of the new phases ϕ_μ and ϕ_{A_t}, $R_{\mu\mu}$ can be as large as 1.85, and the deviations from the SM prediction can be large, if $\tan\beta > 8$. As noticed in Ref. [8], the correlation between the $\mathrm{Br}(B \to X_s \gamma)$ and R_{ll} is distinctly different from that in the minimal supergravisty case. [11]

III. FULLY SUSY CP VIOLATION IN THE KAON SYSTEM

In the MSSM with many new CPV phases, there is an intriguing possibility that the observed CP violation in $K_L \to \pi\pi$ is fully supersymmetric due to the complex parameters μ

and A_t in the soft SUSY breaking terms which also break CP softly, or CP violating $\tilde{g}-q_i-\tilde{q}_j$. Our study on the first possibility in the MMSSM [5] indicates that the supersymmetric ϵ_K (namely, for $\delta_{KM}=0$) is less than $\sim 2\times 10^{-5}$, which is too small compared to the observed value : $|\epsilon_K| = (2.280 \pm 0.019)\times 10^{-3}$. (See also Ref. [12].)

Although one cannot generate enough CP violations in the kaon system through flavor preserving μ and A_t phases in the MSSM, it is possible if one considers the flavor changing SUSY CPV phases. In the mass insertion approximation (MIA), the folklore was that if one saturates the ϵ_K with $(\delta^d_{12})_{LL}$, the corresponding $\epsilon^{'}/\epsilon_K$ is far less than the observed value. On the other hand, if one saturates $\epsilon^{'}/\epsilon_K$ with $(\delta^d_{12})_{LR}$, the resulting ϵ_K is again too small compared to the data. Therefore one would need two independent parameters $|(\delta^d_{12})_{LL}| \sim O(10^{-3})$ and $|(\delta^d_{12})_{LR}| \sim O(10^{-5})$, each of which has a $\sim O(1)$ phase. Recently, Masiero and Murayama argued that such a large value of $(\delta^d_{12})_{LR}$ is not implausible in general MSSM, e.g., if the fundamental theory is a string theory. [13] In their model, the large $(\delta^d_{12})_{LR}$ is intimately related with the large $(\delta^d_{11})_{LR}$, so that their prediction on the neutron edm is very close to the current experimental limit.

In recent work, we pointed out it is possible in fact to generate both ϵ_K and $\mathrm{Re}(\epsilon^{'}/\epsilon_K)$ with a single complex number $(\delta^d_{12})_{LL} \sim O(10^{-2}-10^{-3})$ with an order $\sim O(1)$ phase, if one goes beyond the single mass insertion approximation. [6] Namely, the ϵ_K is generated by $(\delta^d_{12})_{LL}$, whereas $\epsilon^{'}/\epsilon_K$ is generated by a flavor preserving $\tilde{s}_R - \tilde{s}_L$ transition followed by flavor changing $\tilde{s}_L - \tilde{d}_L$ transition. The former is proportinal to $m_s(A_s - \mu\tan\beta)/\tilde{m}^2$ where $\tilde{m}$ is the common squark mass in the MIA. *This induced LR mixing is present generically in any SUSY models, if* $|\mu\tan\beta| \sim 10-20$ *TeV.* The only relevant question would be how one can have an $\sim O(1)$ phase in the $(\delta^d_{12})_{LL}$. For example, the gluino mass can have a CPV phase ϕ_3 which is flavor preserving. After we redefine the gluino field so that the the gluino mass parameter becomes real, the phase ϕ_3 will be tranferred to the $\tilde{g}-q_i-\tilde{q}_j$ vertex, thereby generating CP violations in both flavor preserving and flavor changing gluino mediated strong interactions. [14]

If the KM phase were not zero in this scenario, we cannot use the constraints coming from ϵ_K or ΔM_B, since new physics would contribute to both $\Delta S=2$ and $\Delta B=2$ amplitudes. In particular, even the third or fourth quadrant in the (ρ,η) plane should be possible, in principle. More detailed discussions on these points will be presented elsewhere. Finally let us note that the recent observation on CP asymmetry in $B^0 \to J/\psi K_S$ depends on different CP violating parameter $(\delta^d_{i3})_{AB}$ where $i=1$ or 2, and $A,B = L$ or R, and is independent of the kaon sector we considered here in the mass insertion approximation.

ACKNOWLEDGMENTS

I am grateful to S. Baek, J.-H. Jang, Y.G. Kim, J.S. Lee and J.H. Park for enjoyable collaborations on the works presented in this talk, and also to W.S. Hou and H.Y. Cheng for their nice organization of this conference. This work is supported in part by grant No. 1999-2-111-002-5 from the interdisciplinary research program of the KOSEF and BK21 project of Ministry of Education.

REFERENCES

[1] W. Bernreuther and M. Suzuki, Rev. Mod. Phys. **63**, 313 (1991).
[2] A.G. Cohen, D.B. Kaplan, A.E. Nelson, Phys. Lett. **B388**, 588 (1996).
[3] J.M. Cline and G.D. Moore, Phys. Rev.Lett. **81**, 3315 (1998).
[4] Seungwon Baek and P. Ko, Phys. Rev. Lett. **83**, 488 (1999).
[5] Seungwon Baek and P. Ko, Phys. Lett **B462**, 95 (1999).
[6] S. Baek, J.-H. Jang, P. Ko and J.H. Park, KAIST-TH 99/04, hep-ph/9907572.
[7] A. G. Cohen, David B. Kaplan, F. Lepeintre, Ann E. Nelson, Phys. Rev. Lett.**78**, 2300 (1997).
[8] Y.G. Kim, P. Ko and J.S. Lee, Nucl. Phys. **B 544**, 64 (1999).
[9] D. Chang, W.-Y. Keung and A. Pilaftsis, Phys. Rev. Lett. **82**, 900 (1999).
[10] A. Kagan and M. Neubert, Phys. Rev. **D 58**, 094012 (1998) ; Eur. Phys. J. **C 7**, 5 (1999).
[11] T. Goto, Y. Okada and Y. Shimizu, Phys. Rev. **D 58**, 094006 (1998).
[12] S.A. Abel and J.-M. Frere, Phys. Rev. **D 55**, 1623 (1997).
[13] A. Masiero and H. Murayama, Phys. Rev. Lett. **83**, 907 (1999).
[14] M. Brhlik, G.J. Good and G.L. Kane, hep-ph/9810457.